OIPE
APR 1 9 2001
PATENT & TRADEMARK OFFICE

Atty. Dkt. No. 085874/0304

(4)

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Nicholas P. R. HILL et al.

Title: LOUDSPEAKER DESIGN METHOD

Appl. No.: 09/784,102

Filing Date: February 16, 2001

Examiner: Unassigned

Art Unit: 2856

CLAIM FOR CONVENTION PRIORITY

Commissioner for Patents
Washington, D.C. 20231

Sir:

The benefit of the filing date of the following prior foreign application filed in the following foreign country is hereby requested, and the right of priority provided in 35 U.S.C. § 119 is hereby claimed.

In support of this claim, filed herewith is a certified copy of said original foreign application:

- Great Britain Patent Application No. 0003883.6 filed February 18, 2000.

Respectfully submitted,

Date APR 1 9 2001

By [signature]

FOLEY & LARDNER
Washington Harbour
3000 K Street, N.W., Suite 500
Washington, D.C. 20007-5109
Telephone: (202) 672-5570
Facsimile: (202) 672-5399

Alan I. Cantor
Attorney for Applicant
Registration No. 28,163

This Page Blank (uspto)

The Patent Office
Concept House
Cardiff Road
Newport
South Wales
NP10 8QQ

CERTIFIED COPY OF PRIORITY DOCUMENT

I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

In accordance with the rules, the words "public limited company" may be replaced by p.l.c., plc, P.L.C. or PLC.

Re-registration under the Companies Act does not constitute a new legal entity but merely subjects the company to certain additional company law rules.

Signed M Coakie

Dated 15 February 2001

This Page Blank (uspto)

Patents Form 1/77

Patents Act 1977
(Rule 16)

The Patent Office

21FEB00 E514751-4 D02824
P01/7700 0.00-0003883.6

THE PATENT OFFICE
A
18 FEB 2000
RULE 97
NEWPORT

The Patent Office

Cardiff Road
Newport
Gwent NP9 1RH

Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form).

1. Your Reference	P.6375.GBA
2. Patent application number *(The Patent Office will fill in this part)*	**0003883.6** 18 FEB 2000
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	New Transducers Limited Ixworth House 37 Ixworth Place LONDON SW3 3QH
Patents ADP number *(if you know it)*	7283476002
If the applicant is a corporate body, give the country/state of its incorporation	G.B.
4. Title of the invention	LOUDSPEAKERS
5. Name of your agent *(if you have one)*	
"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	MAGUIRE BOSS 5 Crown Street St. Ives Cambridgeshire PE17 4EB
Patents ADP number *(if you know it)*	07188725001
6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number	Country — Priority application number *(if you know it)* — Date of filing *(day/month/year)*
7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application	Number of earlier application — Date of filing *(day/month/year)*
8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* *a) any applicant named in part 3 is not an inventor, or* *b) there is an inventor who is not named as an applicant, or* *c) any named applicant is a corporate body:)* *See note (d)*	Yes

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form

Description 21

Claims(s)

Abstract

Drawing(s) 13 13

10. If you are also filing any of the following, state how many against each item.

Priority documents

Translations of priority documents

Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*

Request for preliminary examination and search *(Patents Form 9/77)*

Request for substantive examination *(Patents Form 10/77)*

Any other documents *(please specify)*

11. I/We request the grant of a patent on the basis of this application.

Signature Maguire Boss Date 16/02/2000

MAGUIRE BOSS

12. Name and daytime telephone number of person to contact in the United Kingdom Simon K Greene Tel: 01480 301588

Warning

After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. You will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you from applying for a patent abroad without first getting written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.

Notes

a) If you need help to fill in this form or you have any questions, please contact the Patent Office on 0645 500505.

b) Write your answers in capital letters using black ink or you may type them.

c) If there is not enough space for all the relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.

d) If you have answered 'Yes' Patents Form 7/77 will need to be filed.

e) Once you have filled in the form you must remember to sign and date it.

f) For details of the fee and ways to pay please contact the Patent Office.

LOUDSPEAKERS

DESCRIPTION

The invention relates to loudspeakers, more particularly but not exclusively bending wave panel-form loudspeakers e.g. distributed mode acoustic radiators of the general kind described in International patent application WO97/09842.

It is known that the acoustic properties of such distributed mode acoustic radiators differ from those in a conventional pistonic radiator. One principal difference is the diffuse nature of the radiation field of a distributed mode acoustic radiator, which is responsible for their improved performance in areas such as boundary interaction and room coverage.

A conventional pistonic loudspeaker behaves like a point source. The output of a point source is reflected from a boundary and superposed with the direct sound field

to form an interference pattern which is dominated by the path length difference between the direct and reflected sound. Thus, the resulting pressure distribution is determined by the proximity of the loudspeaker to the boundary, and varies only slowly with frequency. Diffusivity of a conventional pistonic loudspeaker is usually considered in terms of the loudspeaker-room interface, where a diffuse field is created after multiple boundary reflections.

In contrast, the diffusivity of a distributed mode acoustic radiator appears to be an inherent property of the direct sound field. The small-scale structure present in the radiation field gives rise to a complex interference pattern.

The essential features of the direct sound field of a distributed mode acoustic radiator are an acoustic power that is a smooth function of frequency at low frequency, combined with a directivity that displays strong small angle fluctuations at higher frequencies. An example of these fluctuations is given in Figure 1, which shows sound pressure level variations on the scale of 10dB in the directivity plot of a typical radiator at 5kHz. Also shown in the figure is the corresponding trace at 6kHz, where the marked difference between the two traces illustrates the

strong dependence of the acoustic output on frequency. Similarly, the interference pattern exhibits a strong dependence on frequency.

When the radiation field is sampled at a single point the small angle fluctuations are manifest as a corresponding fluctuation in the frequency response. This is evident in figure 2, which shows the on-axis frequency response together with the response 10 degrees off axis. The comparison of these two traces also demonstrates the strong dependence of the output on position.

An integration of the frequency response into octave bands has the effect of averaging the small angle fluctuations, giving rise to the smooth directivity plot shown in figure 3. The output of the radiator is therefore very similar to a conventional cone loudspeaker when viewed on an octave band scale, and it is the narrow band detail of the distributed mode acoustic radiation that gives rise to its diffuse boundary interaction.

An object of the invention is to provide a method for the characterisation of the direct sound diffusivity for both conventional pistonic and bending wave panel-form loudspeakers.

According to a first aspect of the invention there is provided a method for measuring the spatial diffusivity of acoustic output from an acoustic device, comprising

measuring the response of the acoustic device at a reference position and comparison positions, and

calculating the correlation between the response at the reference and the comparison positions to provide a measure of the diffusivity.

According to a second aspect of the invention there is provided a method for obtaining a desired level of diffusivity of acoustic output from an acoustic device, comprising the steps of

measuring at least two responses of the acoustic device, one response being a reference response,

calculating the correlation between each measured response and the reference response,

varying at least one parameter of the acoustic device,

remeasuring the said at least two responses and calculating the correlation between the remeasured reference response and the other remeasured responses for each variation,

selecting the or each parameter of the acoustic device which gives a correlation closest to a predetermined optimum value so that the desired diffusivity is obtained.

The responses being correlated may be impulse or frequency responses.

The correlation calculation may use the correlation coefficient (CC) which represents the expectation value of the product of two signals:

Equation one:

$$CC_{xy} = \int_0^\infty X(t) \cdot Y(t) dt$$

x(t), y(t) are the time traces and X(t), Y(t) are the same traces normalised to give an root mean square level of 1. The normalisation ensures that the magnitude of the CC varies between 0 and 1 for perfectly uncorrelated and correlated traces, respectively. A perfectly uncorrelated trace corresponds to a perfectly diffuse source and vice versa.

Preferably, the correlation calculation uses the general cross correlation function (CCF) given below.

Equation 2

$$CCF_{xy}(\tau) = \int_{-\infty}^{\infty} X(t) \cdot Y(t+\tau) dt$$

This function gives the CC as a function of a time delay τ applied to one of the signals. Clearly the CC is equal to CCF at $\tau=0$. The maximum value of the CCF may be

the correlation value compared to the predetermined optimum value.

Alternatively, when performing the calculation of the CCF, the convolution in the time domain may be implemented as a simple multiplication in the frequency domain, and thus an alternative expression for the CCF is given below.

Equation 3

$$CCF_{xy}(t) = IFFT\left(\overline{FFT(X(t))} \times FFT(Y(t))\right)$$

FFT represents the Fourier transform operator, IFFT the inverse Fourier transform, and the horizontal bar represents the complex conjugate operator. The CCF may therefore be determined from measurements of either the time or frequency response.

The correlation may be calculated for each response in a polar data set and displayed as a correlation polar plot. The correlation polar plot may be obtained by the steps of:

choosing a single reference angle, for example the on-axis position,

calculating the correlation between the response at the reference position and another position of the polar data set,

repeating the correlation calculation for every measured response of the polar data set to form a set of correlation responses,

displaying the maximum value of the correlation as a function of angle. Alternatively, the mean value of the correlation may be displayed.

As an alternative or in addition to the correlation polar plot, the mean correlation level of each correlation polar plot may be calculated and may further be plotted as a function of frequency. The combination of the plots of average correlation and the individual correlation polar plots is a comprehensive method since it readily yields the dependence of the diffusivity on frequency and its typical distribution with angle.

In one embodiment, the acoustic device may be a conventional pistonic loudspeaker. The optimum correlation value is preferably one, namely a correlation corresponding to a non-diffuse source.

In another embodiment, the acoustic device may be a bending wave device comprising a panel member for radiating acoustic output and a transducer for exciting bending waves in the panel member. The bending wave device may be a distributed mode acoustic radiators of the general kind described in International patent application WO97/09842.

The optimum correlation value may be zero, representing a perfectly diffuse source.

The parameters being varied are selected from the geometry of the panel member, the material of the panel member, the bending stiffness of the panel member, the boundary conditions of the panel member and the location of bending wave transducers on the panel member. An additional parameter which may be altered is the symmetry of the loudspeaker. The symmetry may be broken by varying the exciter position or alternatively placing the panel in a baffle.

The responses may be filtered to reduce the frequency range of the responses to be correlated. In particular, the responses may be filtered to determine the variation of correlation with frequency. The responses may be filtered using a bandpass, a high pass or a low pass filter. As the filter width is narrowed, the information included in the passband decreases. The filter width may be narrowed to 1-octave or 1/3 octave. A 6^{th} order Butterworth filter may be used. The design of the filter may be determined by the required amplitude response, since the phase response is cancelled by the complex conjugation in the evaluation of the CCF.

The invention is diagrammatically illustrated, by way of example, in the accompanying drawings in which

Figure 1 is a polar plot of the unsmoothed sound pressure level of a distributed mode loudspeaker at 5 and 6 kHz;

Figure 2 is a graph of sound pressure level versus frequency measured on-axis and at 10° off-axis for the loudspeaker of Figure 1;

Figure 3 is a polar plot of the 1-octave smoothed data of Figure 1 (the smoothing is a mean level of the selected band);

Figures 4a and 4b are plots of two impulse responses;

Figure 4c is a plot of the CCF versus time for the responses of Figures 4a and 4b;

Figure 5 is a polar plot of the maximum CCF for a panel and a cone loudspeaker;

Figures 6a and 6b are plots of two impulse responses filtered through 1-octave and 1/3 octave Butterworth 6^{th} order bandpass filters;

Figure 7 is a polar plot of the CCF for filtered output of the panel loudspeaker of Figure 5;

Figure 8 is a graph of the mean CCF versus filter bandwidth;

Figures 9a and 9b are graphs of the mean CCF versus frequency for filtered output of the panel loudspeaker of Figure 5 measured on axis and 35° off-axis;

Figure 10 is a polar plot of the CCF for filtered output of the panel loudspeaker of Figure 5 at four frequencies;

Figure 11 is a graph of the mean CCF versus frequency for filtered output of the cone loudspeaker of Figure 5;

Figure 12 is a polar plot of the CCF for filtered output of the cone loudspeaker of Figure 5 at four frequencies;

Figure 13 is a polar plot of the CCF for filtered output of a second panel loudspeaker at four frequencies;

Figure 14 is a graph of the mean CCF versus frequency for filtered outputs of the panel loudspeaker of Figure 5, the panel loudspeaker of Figure 13 and a third panel loudspeaker;

Figure 15 is a polar plot of the CCF for filtered output of a fourth panel loudspeaker at four frequencies;

Figure 16 a graph of the mean CCF versus frequency for filtered outputs of the panel loudspeaker of Figure 5 and the panel loudspeaker of Figure 15;

Figure 17 is a side view of a panel loudspeaker;

Figure 18 is a polar plot of the CCF for filtered output of the panel loudspeaker of Figure 5 measured 35° off-axis, and

Figure 19 are polar plots of the CCF for filtered output of the panel loudspeaker of Figure 5 driven at the centre and at the edge at four frequencies.

Figures 4 and 5 illustrate the first steps of the method to achieve the desired diffusivity of a source. Figures 4a and 4b shows two impulse responses measured at the on-axis position and 35 degrees off axis respectively. The responses are taken from a polar set of responses for a bending wave action loudspeaker. The CC is calculated using equation 1 to be 0.09 indicating that the correlation between the two responses is small.

Figure 4c shows the CCF calculated using equation 2. It is clear that the maximum CCF value is shifted from the $\tau=0$ position. This is due to the slight difference in the initial time delay of the two measured impulses. As a result, the CC (which is equal to CCF at $\tau=0$) does not represent the true correlation of the two signals. Thus, the correlation between two measured responses may be found by determining the maximum value of the CCF. The maximum

value of the CCF is then calculated for each response in the polar set and plotted as a correlation polar plot.

Figure 5 shows such a correlation polar plot for both a bending wave panel loudspeaker of the general kind described in International patent application WO97/09842 and a conventional cone loudspeaker, each with the following details. The loudspeakers were positioned on a rotating table and the impulse response measured at 1m distance with 5° angular resolution.

Panel 1	Cone
Area = 0.261m^2, Thickness=4mm Bending Stiffness: 13.6 Nm; Surface density: 0.76 kg/m^2;	Model: Mission 750, full range 2-way loudspeaker

The two correlation polar plots, exhibit strikingly different behaviour. Both traces have a value of 1 on-axis, corresponding to the correlation of the reference position with itself. As the angle from the on-axis increases, the correlation of the cone loudspeaker remains high and only decreases significantly for positions behind the front face of the loudspeaker. The panel speaker on the other hand is characterised by a narrow set of angles where the output remains well correlated to the reference position, and outside which the correlation falls off rapidly.

The cone loudspeaker represents a source with a broad angle directivity and high correlation, whereas the panel

loudspeaker exhibits a broad angle directivity but a correlation that falls off rapidly with angle.

Figures 6 to 8 show the effects of filtering the responses before calculating the correlation. Figure 6 shows the effects of filtering the time traces shown in figure 2 into 1/3 and 1 octave bands about 5kHz. The 6^{th} order Butterworth filter used is the standard filter for the MLSSA measurement system. As expected, the wider passband preserves more structure in the impulse response, which in turn preserves a greater difference between the on-axis and 35 degree off axis responses.

The CCF polar plots of the 1/3 and 1 octave band filtered responses of panel 1 are shown in figure 7, where the reference position has been kept on-axis. Compared to the unfiltered broad band data set of Figure 5, it is clear the filtered responses are considerably more correlated. Moreover, as the width of the passband is decreased from 1 octave to 1/3 octave the average correlation level is further increased.

The effect of filter bandwidth on the mean correlation is shown in more detail in figure 8. Here the mean level of the CCF polar plot is plotted as a function of filter width for 4 different orders of Butterworth filter. The broad band correlation level is also shown as a solid straight

line. The traces exhibit similar behaviour as the filter width is increased, showing a decrease in the mean CCF level that ultimately approaches the broadband level. Alternatively, below 1 octave the information contained in the responses decreases rapidly, and the correlation level approaches 1. At such low widths, the Q of the filter can become comparable to that of the panel, in which case the time responses are dominated by the ringing of the filter.

The order of the filter has a relatively minor effect on the correlation level, as it is reduced from 10 to 4. However, as the order is further reduced to 2, the shallow drop off of the response outside the passband leads to an increase in the effective filter width. The result is a marked decrease in the correlation level that becomes more pronounced at low bandwidths.

Thus, the decorrelation of the radiation field is a wide band property, increasing with the more information included in the individual responses. The choice of filter to calculate its frequency dependence is therefore quite arbitrary, and the correlation level should be quoted as a level for a given frequency and passband. The order of filter used does not strongly affect the result, provided it is high enough that the effective width of the filter is

not increased. In the following examples, a 6^{th} order Butterworth filter has been employed.

Figure 9(a) shows the average correlation level as a function of frequency for panel 1 and illustrate the effects of different filters. The solid, dashed and dotted traces correspond to a 1-octave wide bandpass, a high and a low pass filter respectively. For both the bandpass and low pass filter, the correlation level remains close to 1 at low frequencies and only starts to decrease close to 1kHz with the onset of small angle fluctuations in the directivity. As the frequency is further increased, and the fluctuations become more pronounced the correlation falls off, approaching the broadband level at high frequencies. In contrast, the high pass filter remains almost constant over the complete band. This demonstrates an important property of such speakers, namely that the high frequency information dominates any diffuseness, and the maximum frequency included in the filter determines the correlation level.

Figure 9(b) shows a similar plot to 9(a), where the reference position has been moved 35 degrees off axis. It is clear that there is very little difference between the two graphs demonstrating that the average correlation level

is not sensitive to the reference position, making it a robust measure of the diffusivity.

The filtered traces presented in the following examples are limited to the 1-octave bandpass filter, since the results produced are the most straightforward to interpret. It will be appreciated that for any specific case, the investigation may benefit from additional calculations based on high or low pass filters. However, these filters alone are likely to be less sensitive to some specific types of decorrelation. One example of this is when the decorrelation is concentrated in a relatively narrow frequency band, such as a bad crossover arrangement between of a pair of drivers. The condition would be obvious in the bandpass approach, but is more likely to be obscured by the broadband filters.

The mean correlation level plotted as a function of frequency in figure 9 is shown in more detail in figure 10. Here the CCF polar plots are plotted for filter centres of 500Hz, 1kHz, 5kHz, and 10kHz. At the lowest frequency the CCF polar plot is approximately circular, except directly off axis, and remains so up to 1kHz. Above 1kHz, the general trend of the plot is to narrow from the off axis positions. At the highest frequencies the 5-degree resolution of the polar plot is not sufficient to map the

fine details of the trace, though the general trends and the average level are obvious. The correlation level falls off rapidly with increasing angle from the on-axis reference position, reaching its minimum approximately 90 degrees off axis. As the angle is further increased behind the panel the correlation level rises again.

Figure 11 shows the mean correlation of the cone loudspeaker, where the average is taken over the front hemisphere, since this loudspeaker is designed to radiate only over this region. The mean correlation level remains close to 1 over the whole frequency band, demonstrating the highly correlated output of the loudspeaker. However, at the highest frequencies there is a small drop in the correlation, that might be an indication of cone break up or some other decorrelating mechanism.

The CCF polar plots relating to the cone loudspeaker are shown in figure 12. The correlation level over the front hemisphere remains close to unity over the complete frequency range. Only at 10kHz is there any noticeable drop away from the reference position, which is responsible for the small drop in the mean correlation level shown in figure 11.

The effects of varying panel parameters to achieve a desired level of diffusivity are shown in Figures 13 to 16. The following panels of the same material were used:

	Panel 1	Panel 2	Panel 3	Panel 4
Area (m^2)	0.261	0.059	0.035	0.261
Thickness (mm)	4	4	4	4
Bending Stiffness(Nm)	13.6	13.6	13.6	0.68
Surface density(kg/m^2)	0.76	0.76	0.76	0.406

Panels 2 to 4 differ from panel 1 by at least one parameter e.g. area or bending stiffness. For panels 2 to 4, a correlation polar plot was derived in the same way as the polar plot of Panel 1 in Figure 10. The results of the correlation analysis for each panel may then be compared to determine which of panels 1 to 4 has a correlation closest to the predetermined optimum value. For example, to achieve a perfectly diffuse source, a correlation of 0 is optimum.

Figure 13 shows CCF polar plots for panel 2 and the plots are remarkably similar to those of the Panel 1 shown in figure 10. Thus although a decrease in the size of a panel might be expected to increase its CCF levels, since a small panel has scarcer modal distribution, this does not appear to be the case.

Figure 14 supports the findings of Figure 13 and shows the mean CCF frequency responses against frequency for Panels 1, 2 and 3. The traces show some minor differences,

however it is clear that the overall behaviour of the mean CCF levels is very similar. Accordingly, panels 1 to 3 are all equally diffuse. This leads to a surprising conclusion that the size of the panel does not strongly influence the CCF levels and thus is not useful as a parameter to vary to achieve a desired diffusivity.

Figure 15 shows four CCF polar plots of panel 4 which is approximately 20 times less rigid than Panel 1. The plots differ greatly to those of the Panel 1 in Figure 10. The rapid fall-off with angle of the CCF for panel 1 is replaced by an almost constant CCF level that only decreases at the farthest off-axis positions. Thus there is a correlated sound field around this speaker

Figure 16 compares the mean CCF frequency response of Panel 4 with Panel 1. For Panel 4, the mean CCF levels stay closer to unity than for Panel 1 over the whole frequency band, with only a slow fall-off at higher frequencies. These high CCF levels that result from the correlated sound field. Thus, panel 1 is preferable to panel 4 since panel 4 has a correlated sound field.

Clearly, material properties appear to be a much greater factor than the panel area in the determination of the CCF levels.

From a comparison of the polar plots of Figures 10 and 12, it is clear that the symmetry of the system also effects the correlation. A conventional cone loudspeaker is not a symmetrical system, since the loudspeaker is designed to radiate only the front hemisphere. The lack of symmetry in the system is reflected in the lack of symmetry of the front and rear radiation in the polar plot of Figure 12.

In contrast as is clearly seen in Figure 17 a panel loudspeaker has two lines of symmetry of, namely a plane of symmetry parallel to the panel surface and a plane perpendicular to the panel. The physical symmetry of the panel loudspeaker is reflected in the CCF polar plots both in Figure 10, where the reference position is fixed on-axis and in Figure 18, where the reference position has been moved 35 degrees off-axis. In both Figures, the forward radiation at a particular angle is approximately equivalent to the rear radiation at the symmetric position which reflects the parallel plane of symmetry. In addition, Figure 18 suggests the presence of a reflection symmetry about the perpendicular plane, with corresponding structure either side of the on-axis line.

The symmetry about the plane perpendicular to the panel surface is dependent on the exciter component on the

panel. When the exciter is attached to the panel close to its centre, the natural symmetry of the plate is preserved.

Figure 19 shows the CCF polar plots for Panel 1 with the single exciter placed either at the centre of the panel or one of the edges. The reduction in the number of symmetries is clearest at the lower frequencies, though the picture becomes less clear at high frequency, where the 5 degree resolution is unable to resolve all of the structure in the polar plot. Thus, when the exciter is placed in a strongly asymmetric position this symmetry is broken and only the front to back symmetry persists.

It will be appreciated that the symmetry of the system may be broken in other ways, e.g. in a closed-back panel loudspeakers.

Figure 1 Directivity at 5 and 6 kHz. The data is unsmoothed.

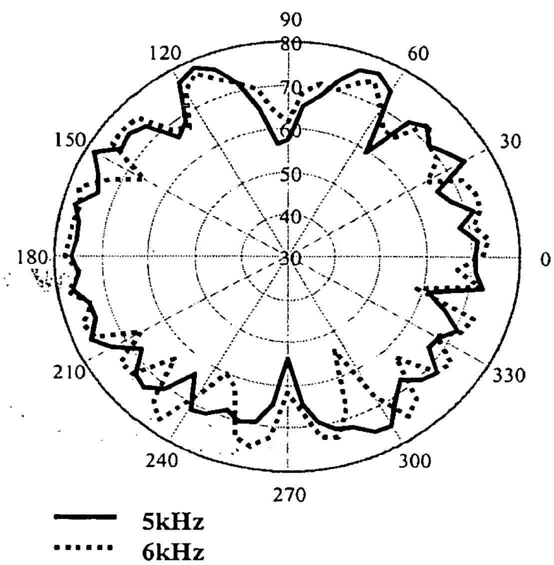


Figure 2 On-axis and 10° off-axis frequency responses

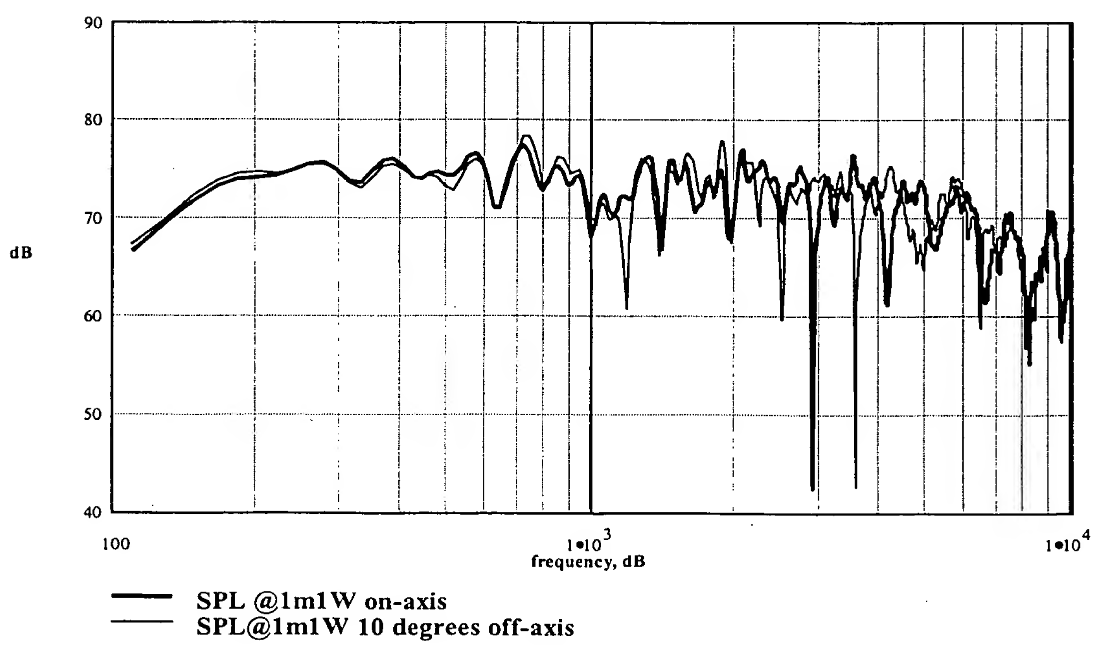
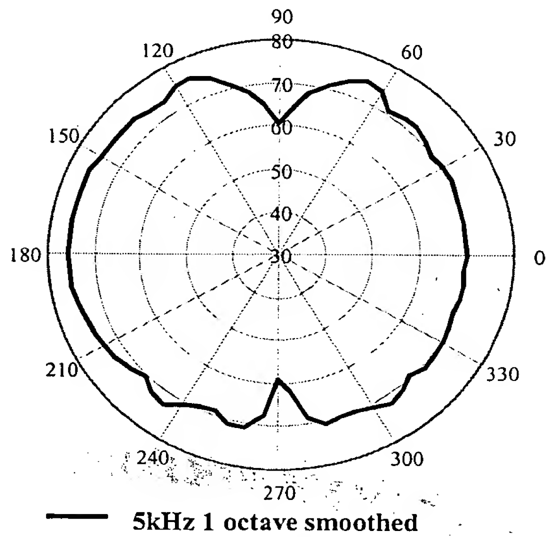


Fig.3 Directivity of 1 octave smoothed data (same data as in Fig.1). The smoothing is a mean level over the selected band.



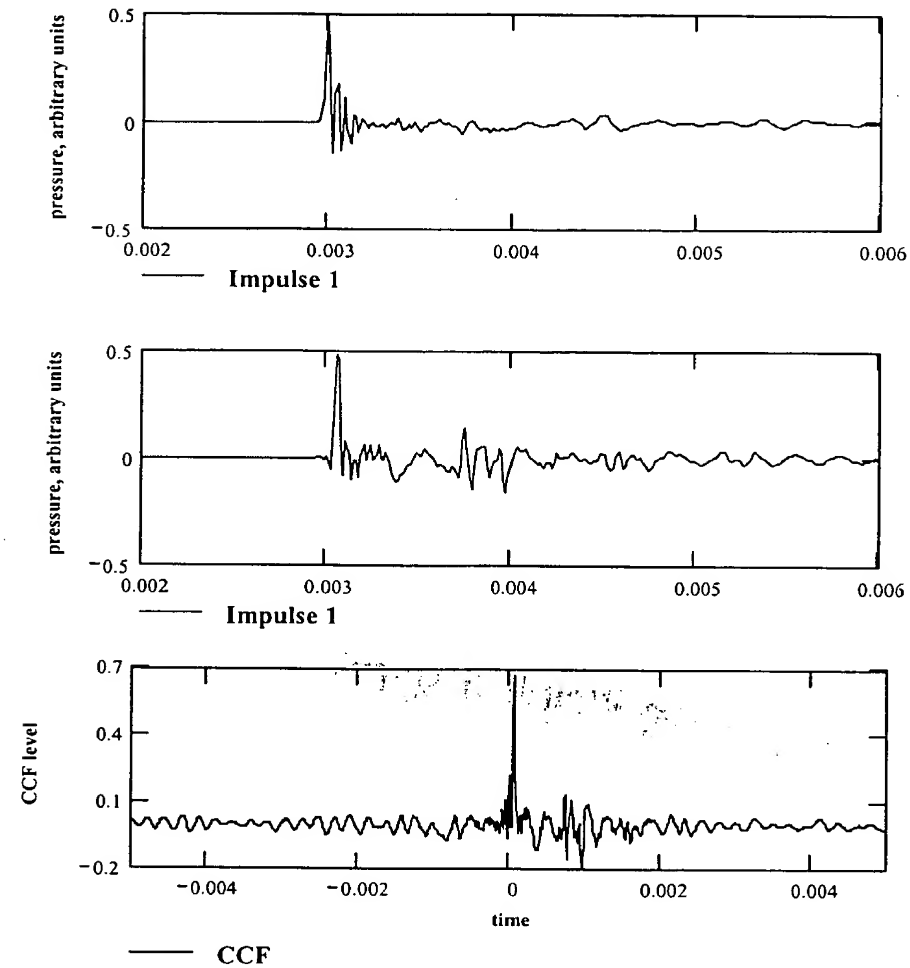


Figure 4 Impulse Responses (top and middle graphs) and their Cross-correlation Function (bottom graph). Impulse 1 and Impulse 2 are taken from a polar data set and have 35° angular spacing between them.

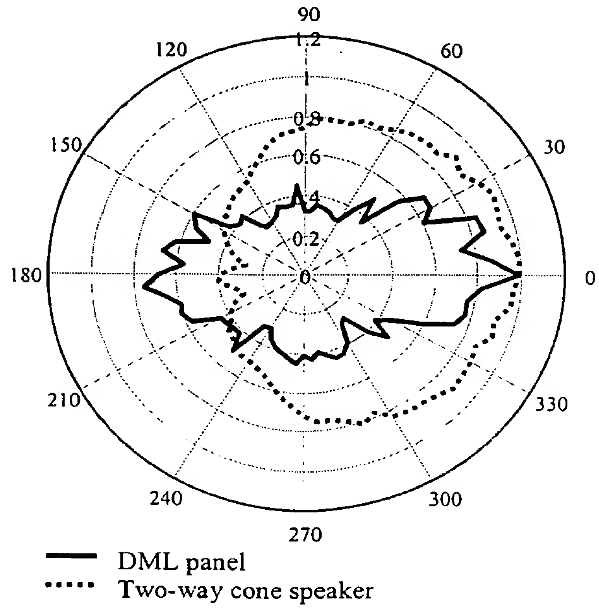


Figure 5 Maximum Cross-Correlation polar plot. On-axis response is compared with all other responses of the polar data set.

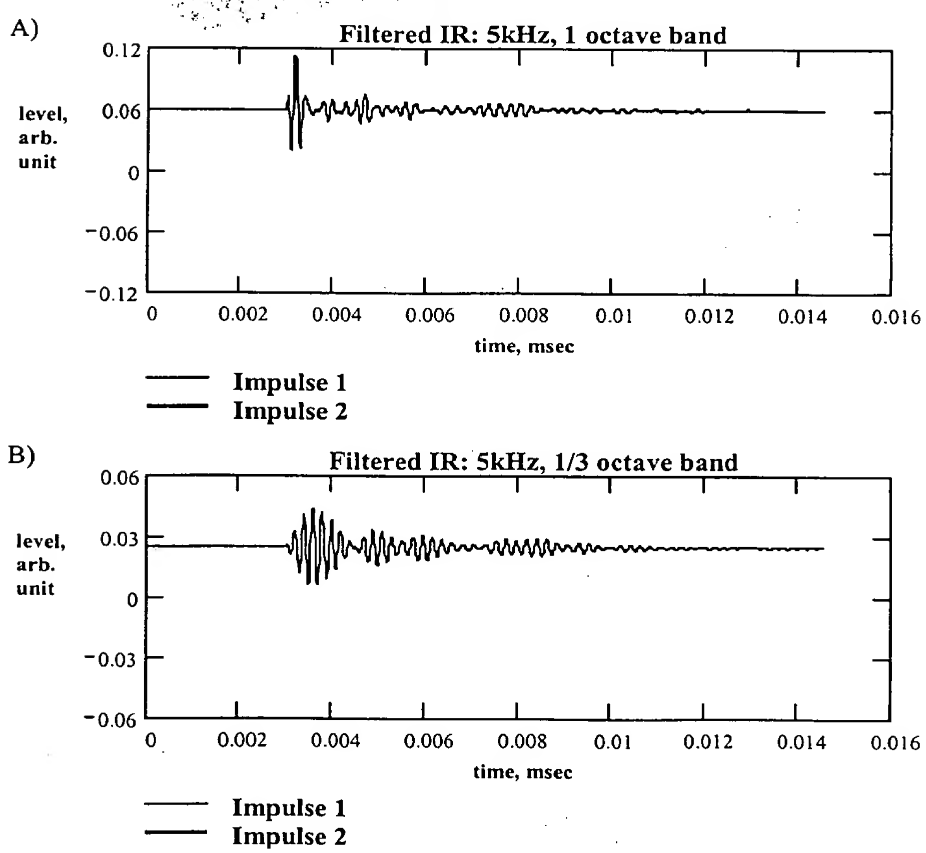


Figure 6 Filtered Impulse responses (see Figure 4 for original responses). The filter is Butterworth 6[th] order bandpass with linear phase. Impulse 1 is on-axis, Impulse 2 is 35° off-axis

This Page Blank (uspto)

5/13

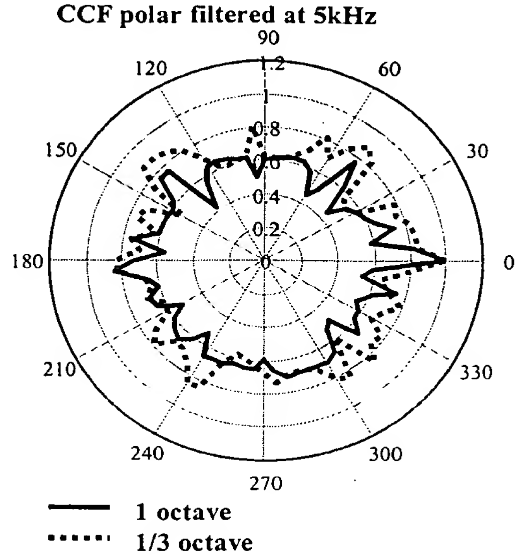


Figure 7 Cross Correlation polar plots of the polar data set. The data was filtered with a Butterworth bandpass filter (6th order) 1 and 1/3 octave wide at 5 kHz centre frequency.

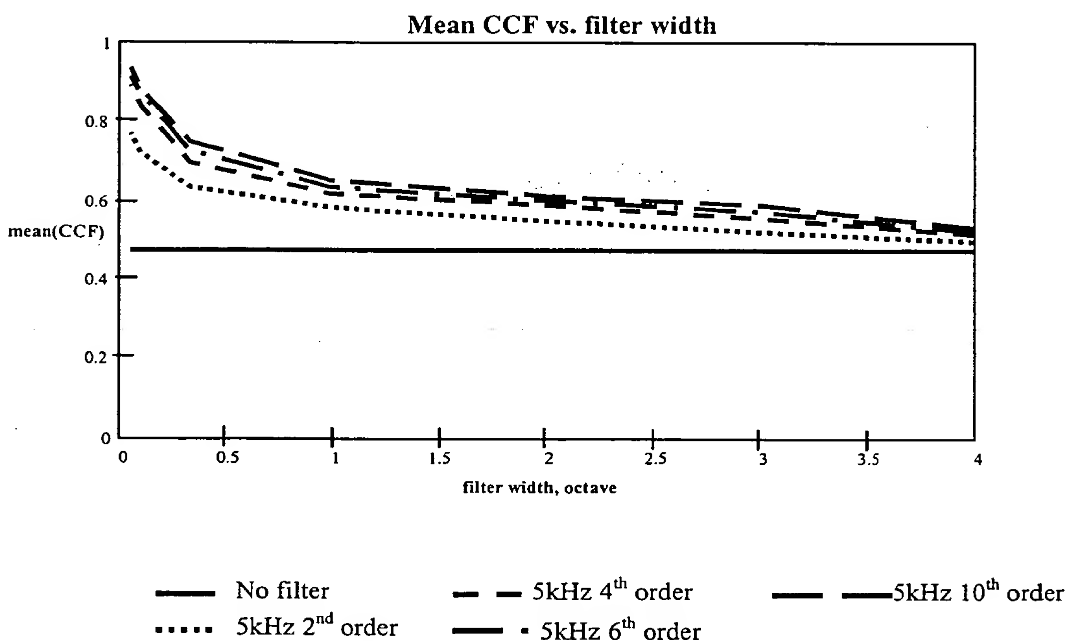
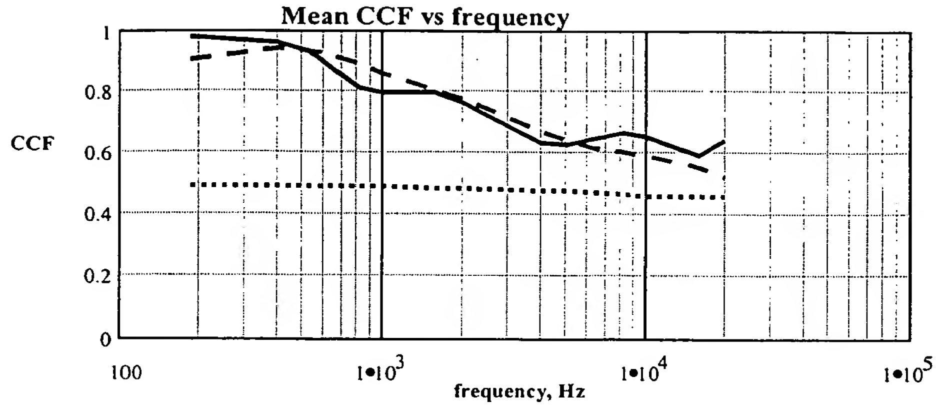


Figure 8 Mean CCF level (average from CCF polar plot) vs. filter bandwidth. Centre frequency is 5kHz. The graphs are presented for various filter orders.

This Page Blank (uspto)

a)



b)

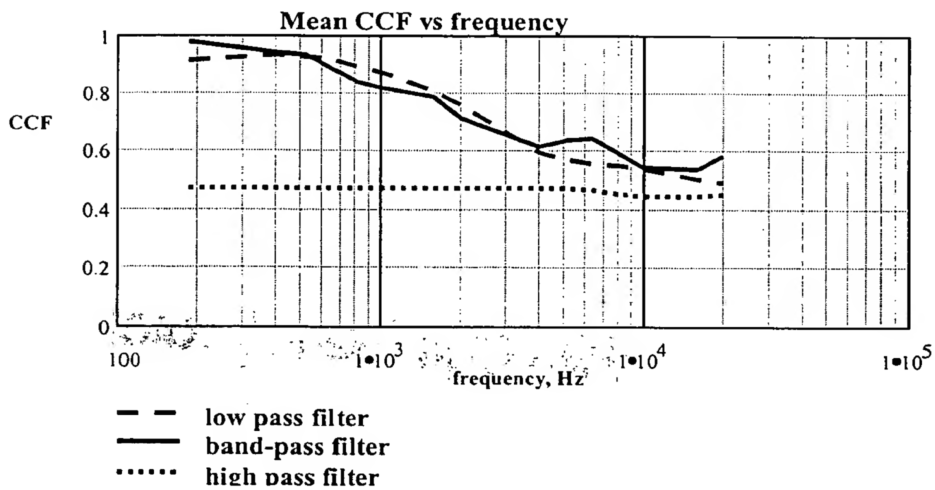


Figure 9 Mean CCF frequency dependence of the Panel 1. Traces in the graph (a) correspond to on-axis reference position, traces in (b) - 35° off-axis reference position.

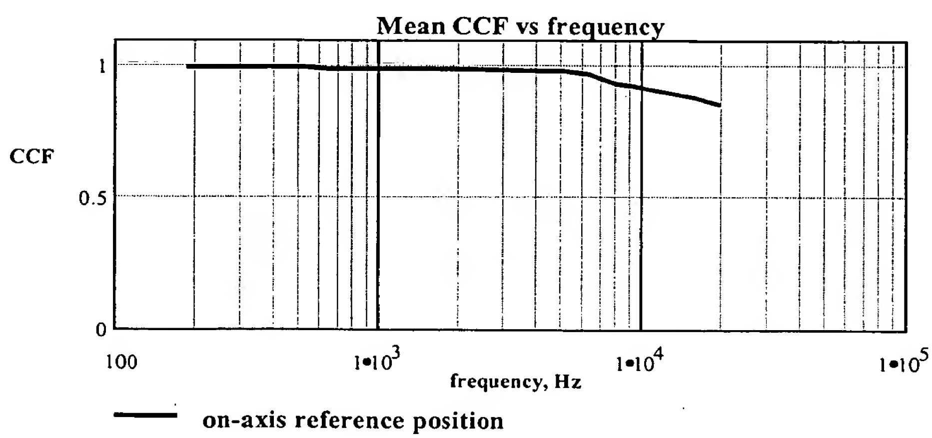


Figure 11 Mean CCF frequency dependence of the Cone loudspeaker. The data was filtered with a 1 octave Butterworth 6[th] order bandpass filter

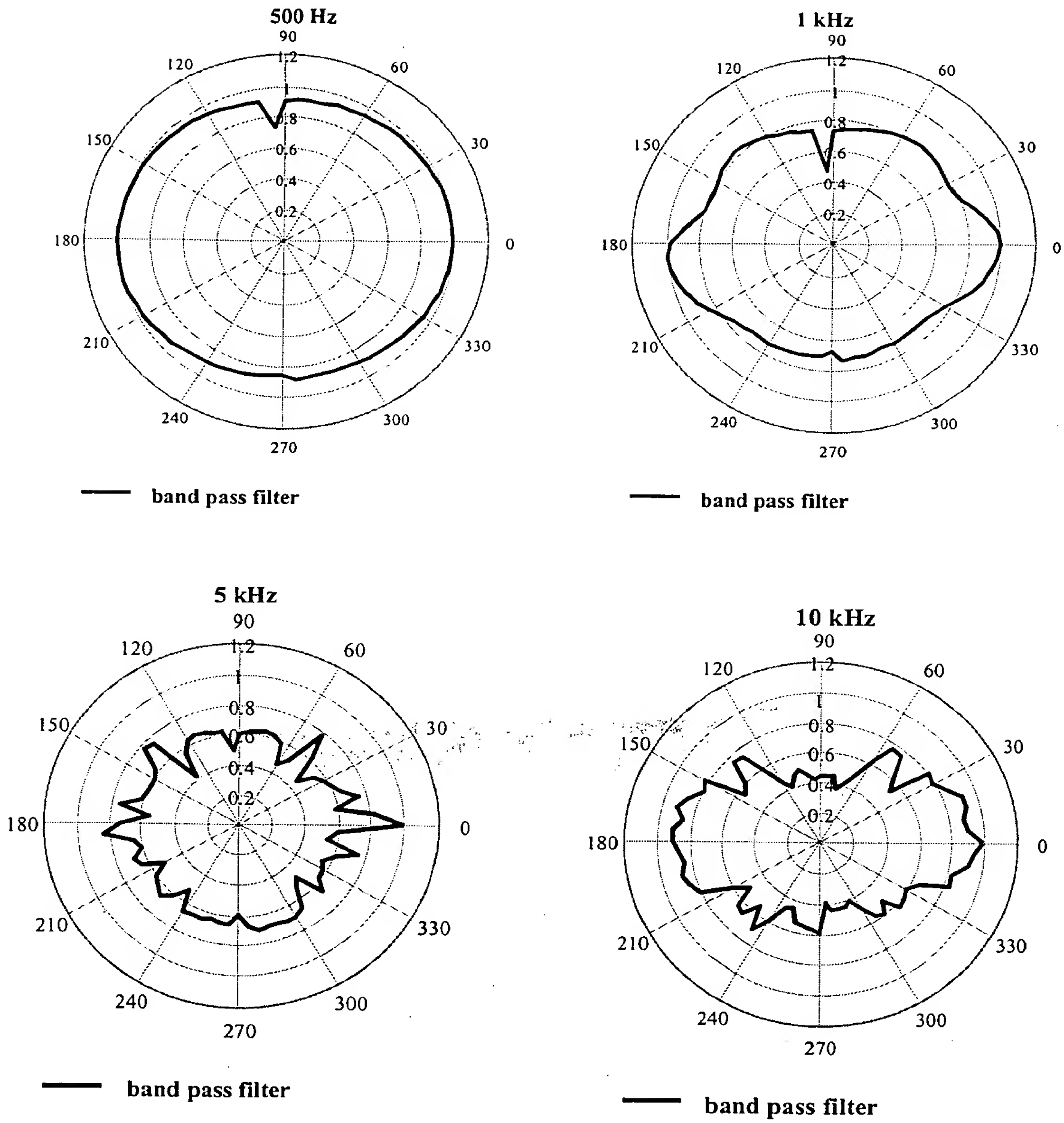


Figure 10 CCF polar plots of the Panel 1. The reference position is on-axis.

This Page Blank (uspto)

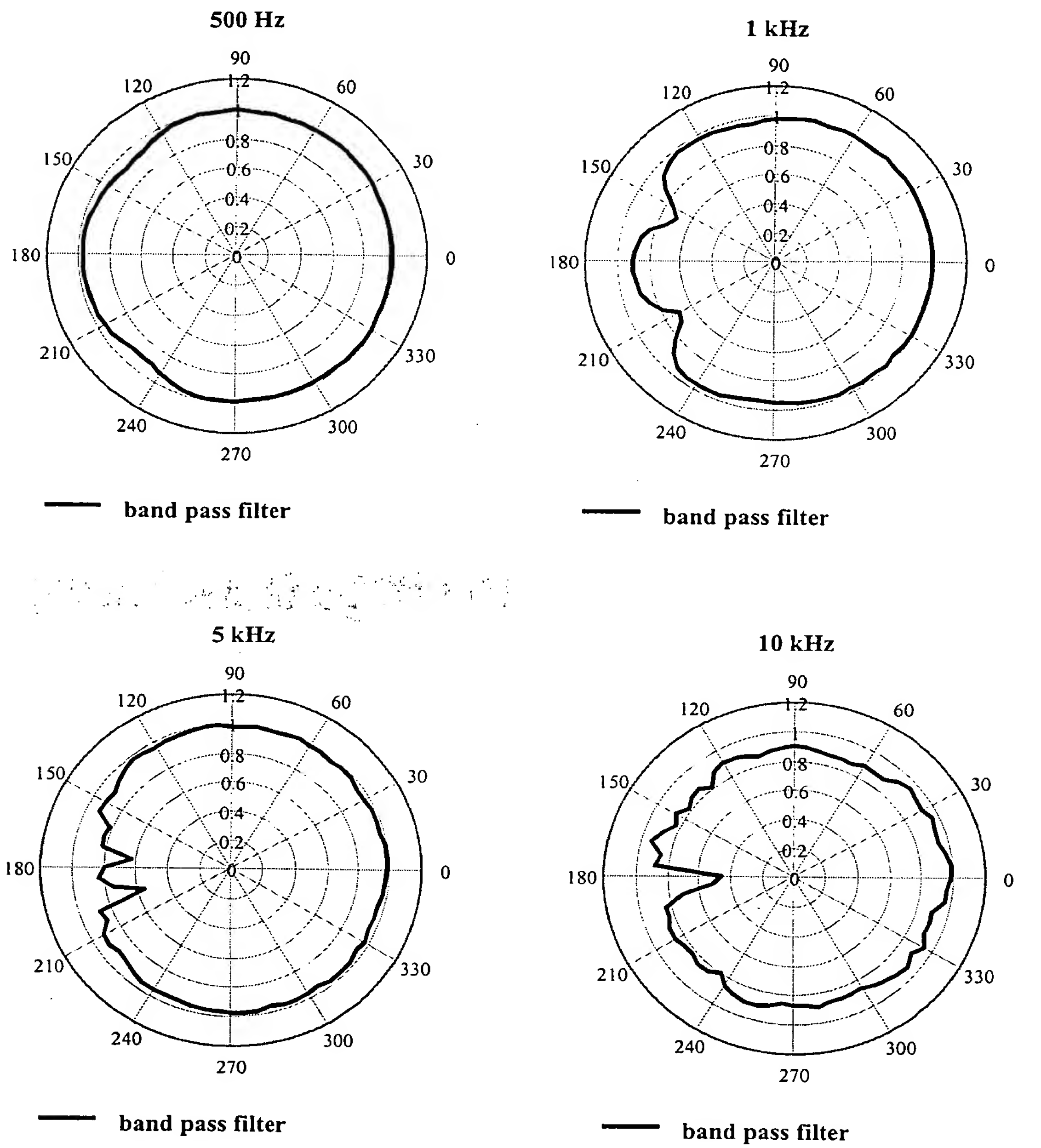


Figure 12 CCF polar plots of the Cone loudspeaker. The reference position is on-axis

This Page Blank (uspto)

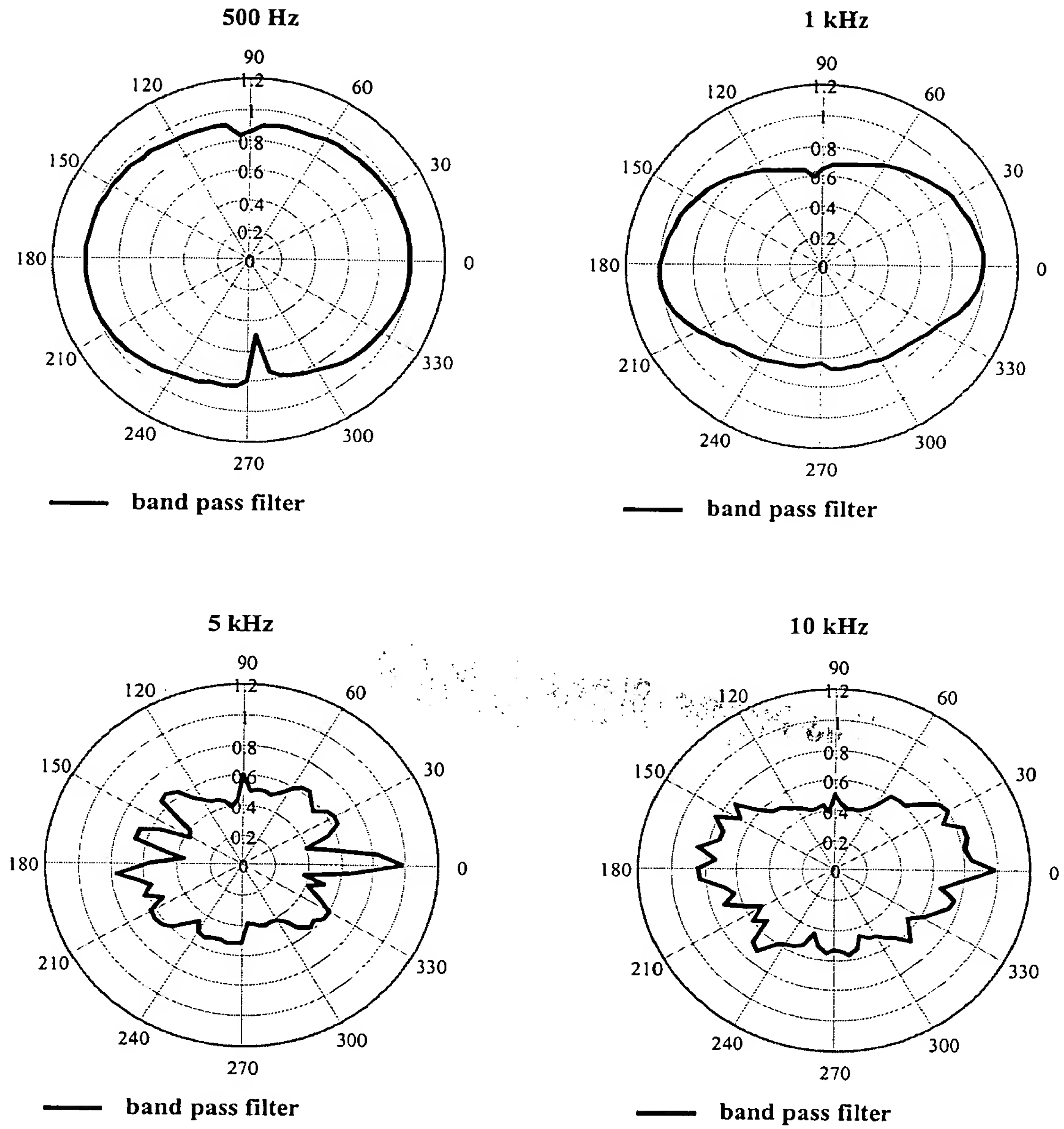


Figure 13 CCF polar plots of the Panel 2.

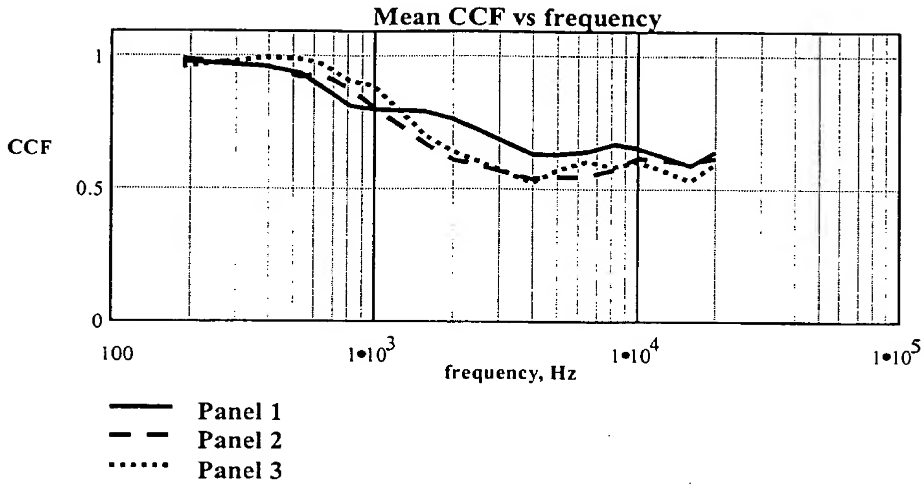


Figure 14 Mean CCF frequency dependencies of the Panel 1, Panel 2 and Panel 3. The traces are plotted for the bandpass filtered data.

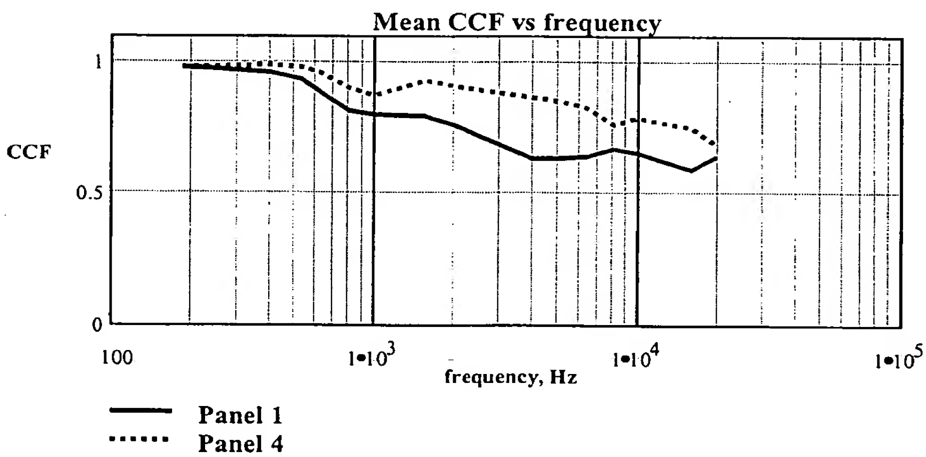


Figure 16 Mean CCF frequency dependence of the Panel 4 plotted together with the trace for the Panel 1 for comparison. The data is filtered with a bandpass filter

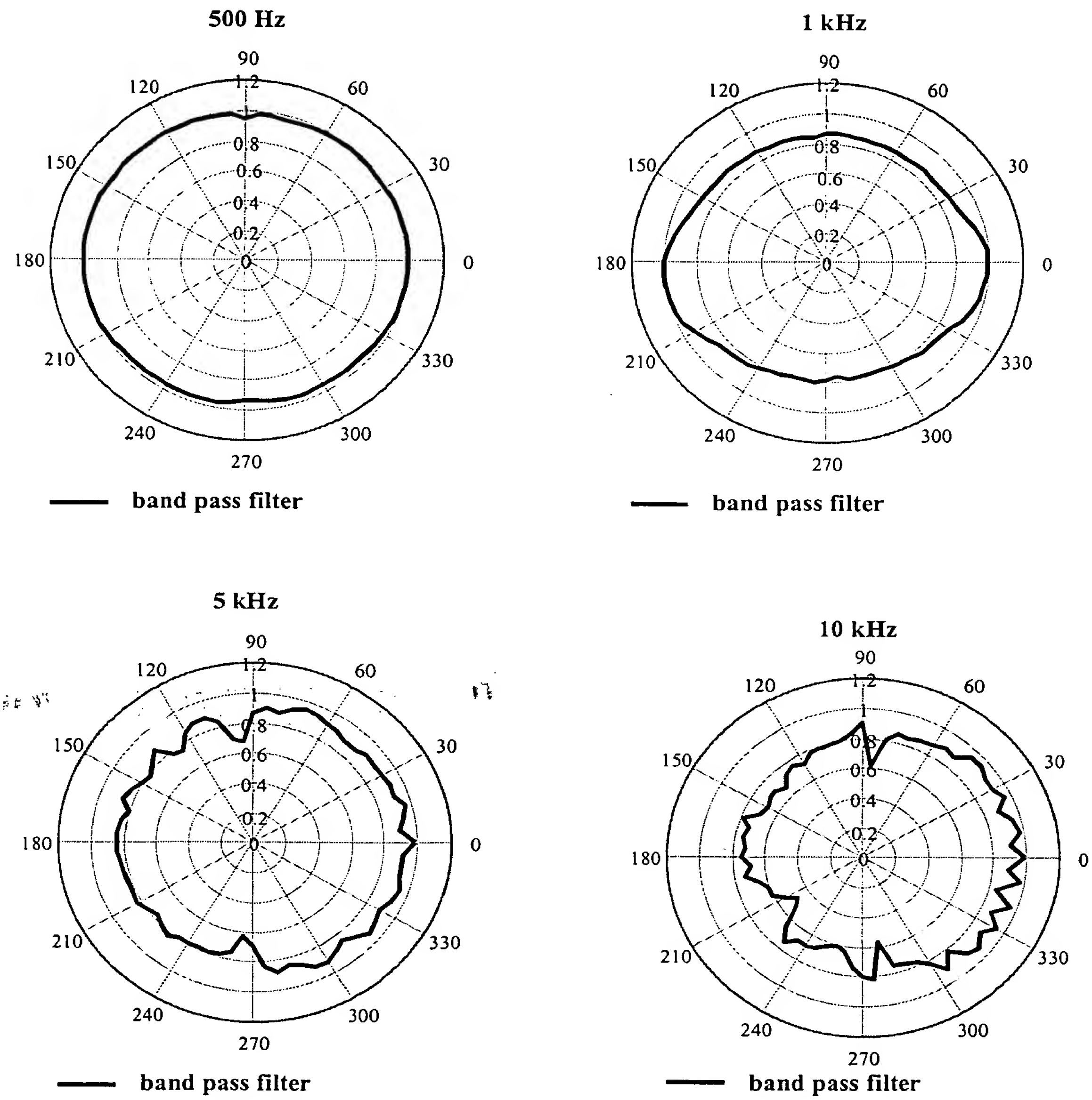


Figure15 CCF polar plots of the Panel 4

This Page Blank (uspto)

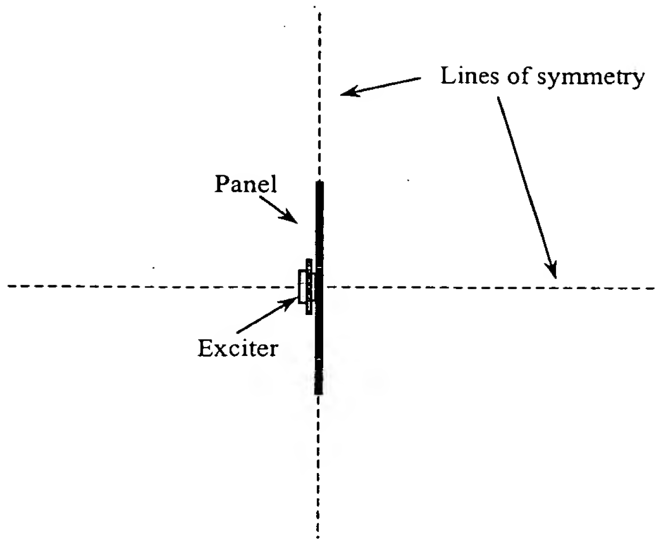


Figure 17 CCF lines of symmetry

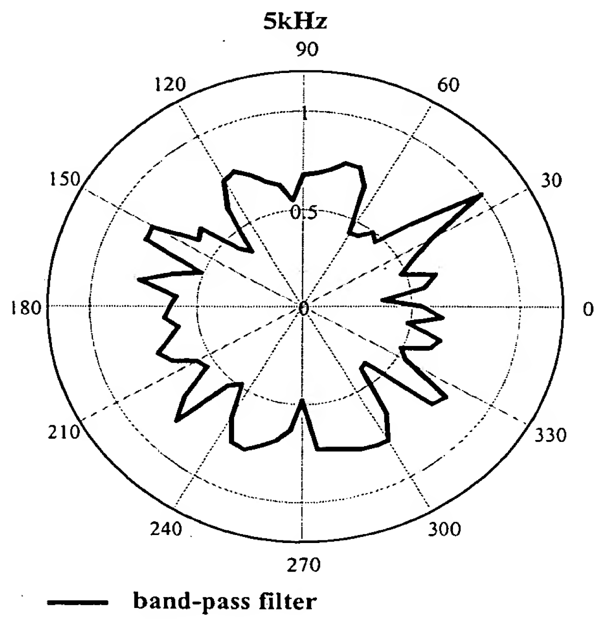


Figure 18 CCF polar plot of the Panel 1. The reference microphone position is 35° off-axis.

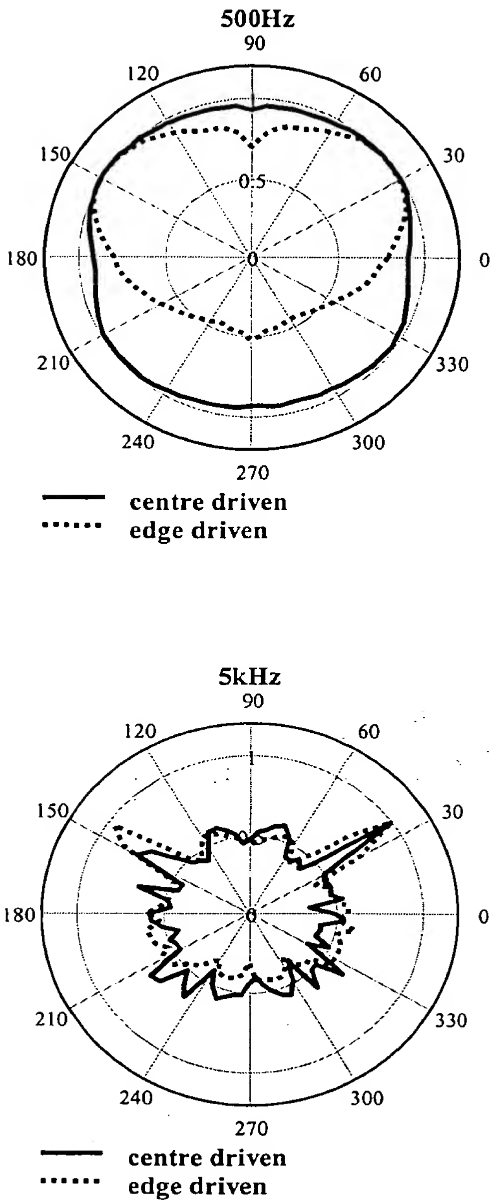


Figure 19 CCF polar plots of the Panel 1 driven at the centre and edge. The filter used is bandpass 1 octave.

FOLEY & LARDNER
3000 K Street, N.W., Suite 500
Washington, DC 20007-5109
Serial No. 09/784,102 Filed: Feb. 16, 2001
Docket No. 085874/0304